**UNITED STATES ENVIRONMENTAL PROTECTION AGENCY**
**REGION IX**
**75 Hawthorne Street**
**San Francisco, California 94105**

DRAFT Version 5~~4~~ - ~~May 18~~June 12, 2017

Derek J. Robinson, BRAC Environmental Coordinator
Department of the Navy
Base Realignment and Closure
Program Management Office West
33000 Nixie Way, Building 50
San Diego, CA 92147

SUBJECT: Radiological cleanup standards for soil and USEPA PRG Calculator
Hunters Point Naval Shipyard, San Francisco, California

Dear Mr. Robinson:

The Department of the Navy ("Navy") has established, with regulatory approval, radiological Remediation Goals or release criteria for Radionuclides of Concern (RO~~o~~Cs) in Records of Decision (RODs) for all parcels (Parcels B, C, D-1, D-2, E, E-2, F, UC-1, UC-2, and UC-3) of the Hunters Point Naval Shipyard (HPNS), San Francisco, California. These Remediation Goals or release criteria for these RODs are the same as the release criteria listed in Table 1 of the 2006 *Action Memorandum* for the HPNS *Basewide Radiological Removal Action*.

Superfund Regulations in the National Contingency Plan (NCP) have defined the protective range of excess cancer risk as a probability that a person exposed to radioactive and chemical contaminants will have an additional one in ten thousand to a one in a million chance of developing cancer (technically known as the $10^{-4}$ to $10^{-6}$ cancer risk range).

The U.S. Environmental Protection Agency (USEPA) developed the *Preliminary Remediation Goals (PRGs) for Radionuclides Electronic Calculator*, known as the "PRG calculator" as one tool for estimating risk from exposure to radiological contamination. In December, 2016, EPA updated its soil PRG Calculator. This letter and attachment describe an updated estimate of risk associated with the Remediation Goals for all Parcels at the Hunters Point Naval Shipyard using site-specific factors, the approach recommended in the *PRG Calculator User's Guide*. All Parcels in the HPNS are required to implement institutional controls that include installing durable covers and prohibit growing plants for consumption, except in raised planters with imported soil. The estimates incorporate these protective measures.

Using this realistic scenario, the current version of the soil ~~Rad~~ PRG calculator estimates that the risks associated with the Remediation Goals (RG's) for each of the RO~~o~~Cs fall within the NCP risk range of $10^{-4}$ to $10^{-6}$ for a residential soil exposure scenario, the most protective option. Typically, individual survey units would contain two to four RO~~o~~C's. USEPA found that in addition, even if all HPNS RO~~o~~Cs were present at the Remedial Goal concentrations, the total combined risk would also still fall with within the risk range of $10^{-4}$ to $10^{-6}$. These RG's apply to concentrations found above background levels.

The attachment and appendices to this letter gives more details about USEPA's analysis. Please contact me at 415-947-4187 or [ HYPERLINK "mailto:lee.lily@epa.gov" ] if you would like to discuss this issue further.

Sincerely,

Lily Lee
Remedial Project Manager

Attachments

Cc. Juanita Bacey, State of California Department of Toxic Substances Control
Tina Low, State of California Regional Water Quality Control Board
Amy Brownell, San Francisco Department of Public Health

**ATTACHMENT**

**USEPA Region 9 Evaluation of Hunters Point Naval Shipyard Radiation Cleanup Standards for Soil**

## 1. Introduction and Summary

The Hunters Point Naval Shipyard (HPNS) is a former military base in San Francisco, California. It was used by the Navy as a naval submarine and ship repair facility from 1945 until 1974 and was also the site of the Naval Radiological Defense Laboratory from 1948 to 1969. In 1989, U.S. EPA placed the Shipyard on its National Priorities List, which is a list of federal Superfund sites in the United States.

The Navy is the lead agency responsible for the investigation and cleanup of HPNS. As part of the process, EPA and its regulatory agency partners (e.g., California Department of Toxic Substances Control and Regional Water Quality Control Board) oversee and enforce Navy compliance with the Comprehensive Environmental Response, Compensation, and Liability Act (commonly called the Superfund law) to ensure the cleanup at HPNS protects human health and the environment. The Navy and regulatory agency partners work together to decide how to address the contamination. The Navy also gathers community input through a public process.

EPA uses the best available science to develop guidance for cleaning up sites, such as HPNS, that are contaminated with radioactive materials. EPA's goal for the HPNS cleanup is to ensure that the community is protected from exposure to radiation and that the site can be used for work, recreation, and residential purposes.

EPA assesses the health effects of radiation at a site by calculating the "excess cancer risk" posed by radioactive contamination. Excess cancer risk is the additional probability that a person exposed to contamination will develop cancer over a lifetime. Superfund regulations in the National Contingency Plan have defined the protective range of excess cancer risk as a probability that a person exposed to radioactive and chemical contaminants will have between an additional one in ten thousand and a one in a million chance of developing cancer (technically known as the $10^{-4}$ to $10^{-6}$ cancer risk range). When calculating this range, EPA uses assumptions about exposure that are much higher than most people's actual exposure. This means that EPA overestimates risk to most people to make sure that cleanups are sufficiently protective.

EPA reviews the Navy's cleanup report for each survey unit (small area of land or part of a building) of HPNS using the current version of the EPA risk model to make sure that radiation levels are within the protective $10^{-4}$ to $10^{-6}$ cancer risk range. This ensures that any land that is transferred to the City of San Francisco for new use meets appropriate levels for protectiveness with regard to radiation. In addition to removing radiological contamination above cleanup goals, the Navy is installing a protective cover over the whole site. The Navy is also developing a plan, which EPA will review, that ensures the Navy or City will maintain and inspect the cover indefinitely.

EPA's risk models have changed over time as radiation science continues to improve. In addition, Navy cleanup requirements have changed over time. EPA has incorporated the latest models and cleanup requirements into its review process to ensure the HPNS cleanup continues to be protective of human health and the environment. EPA has reviewed the Navy's past HPNS cleanup reports, applying the current EPA risk model for soil, and found that the Navy's earlier soil cleanup work has achieved the cleanup level needed to protect human health and the environment.

## 2. **Background information**

The Department of the Navy ("Navy") has established, with regulatory approval, radiological Remediation Goals (RG's), or release criteria, in Records of Decision (ROD's) for all parcels (Parcels B, C, D-1, D-2, E, E-2, F, UC-1, UC-2, and UC-3) of the Hunters Point Naval Shipyard (HPNS), San Francisco, California (See, for example, Navy, 2009). These Remediation Goals are the same as the release criteria listed in Table 1 of the 2006 *Action Memorandum* for the HPNS *Basewide Radiological Removal Action* (Navy, 2006).

Regulations in the National Contingency Plan (NCP) have defined the protective range of excess cancer risk as a probability that a person exposed to radioactive and chemical contaminants will have an additional one in ten thousand to a one in a million chance of developing cancer (technically known as the $10^{-4}$ to $10^{-6}$ cancer risk range).

The U.S. Environmental Protection Agency (USEPA) developed the *Preliminary Remediation Goals (PRGs) for Radionuclides Electronic Calculator*, known as the "PRG calculator" as one tool for estimating risk from exposure to radiological contamination (USEPA, 2017).[1] In December, 2016, EPA updated its soil PRG Calculator.

The RG's represent concentrations above background levels, which are determined based on measurements at reference areas. The activity concentrations of radionuclides in each medium should then be compared with site-specific background concentrations of those radionuclides (i.e., radionuclide concentrations in environmental media not related to site operations or releases). See Appendix A for more details about the Hunters Point Naval Shipyard site-specific approaches to determining background levels.

The Navy uses a "not-to-exceed" approach at HPNS and removes soil found above RG's in its cleanup actions. See, for example, Parcel B *Radiological Removal Action Completion Report*, which describes the cleanup "to prevent exposure to residual ROCs in concentrations that exceeded remediation goals . . . ." (Navy, 2012)

Please note that radiological risk from buildings are addressed separately from soil and is not the subject of this letter and attachment. USEPA Guidance recommends estimating risk from

[1] Please note: The soil *PRG Calculator Users Guide* states the following: "This guidance document sets forth EPA's recommended approaches based upon currently available information with respect to risk assessment for response actions at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites (commonly known as Superfund). This document does not establish binding rules. Alternative approaches for risk assessment may be found to be more appropriate at specific sites . . . ." (USEPA, 2017)

radiological contamination in buildings using the Buildings PRG Calculator, which is a different model.

## 3. Site-Specific Factors

The USEPA *PRG Calculator Users Guide* recommends using site-specific factors:

> "Inclusion or deletion of exposure pathways should be based on site-specific conditions, including but not limited to local hydrology, geology, potential receptors, and current and potential future land use, among other factors. Accordingly, some exposure pathways may not be appropriate for a given site and may be deleted; in such cases, the Region should explain its justification for doing so and provide specific supporting data and information in the administrative record documents that discuss the risk assessment (e.g., Baseline Risk Assessment, RI, ROD, etc.)." (USEPA, 2017)

All Parcels in the HPNS are required to implement institutional controls that include installing and maintaining "Durable Covers" on all Parcels listed above and prohibiting growing of plants for consumption except in raised planters. The Navy and City also develop ~~a~~ plans, which EPA will review, that ensure the Navy or City will maintain and inspect the cover indefinitely. These are included in the RODs and the Risk Management Plans for individual Parcels. (See, for example, Navy, 2009, *Amended ROD for Parcel B*, and Geosyntec, Inc., 2015, *Risk Management Plan for Parcel UC-1 and UC-2*.) The PRG Calculator site-specific resident equation inputs for soil incorporate these protective measures.

Therefore, for each radionuclide, the following parameters were determined to be the most realistic scenario for calculating the risk values:

1. Even though the future land use plans for HPNS include residential, industrial/commercial, and recreational uses, to be most conservative, the PRG Calculator site-specific equation inputs assume a residential scenario, the most sensitive land use. EPA uses the residential soil exposure scenario as the most protective option because potential exposure for residents is greater than for worker or recreational exposure scenarios.

2. [Move to appendix] The "Durable Cover" can be two feet of soil, six inches of asphalt, or a building foundation. Among these options, the asphalt cover is the form of Durable Cover that provides the least amount of shielding. Therefore, to be most conservative, the PRG Calculator estimate assumes an asphalt cover. See, for example, the *Parcel B Remedial Design*, which requires the following:

   > "The newly constructed asphalt pavement cover will extend between the existing buildings over the site to prevent contact with the potentially contaminated soil beneath. The asphalt pavement cover will consist of a minimum 4 inches of ABC [aggregate base course] material and a

minimum 2 inches of an AC [asphaltic concrete] wear surface, for a total cover thickness of 6 inches." (Navy, 2010)

All other Parcels named above have an equivalent requirement of at least this level of protection. Appendix B has calculations for a six-inch thick asphalt cover to show that it has equivalent gamma shielding to a 23~~5~~ cm soil cover (which is approximately 9 inches). The PRG calculator only allows entries in 10 cm increments, so the estimate assumes a 20 cm soil cover~~, which may be roughly equivalent to 4.8-inch-thick asphalt cover,~~ to be conservative.

3. [Move to appendix] The PRG Calculator equation input assumes no inhalation exposure, due to the Durable Cover requirement that applies to all Parcels named above.

4. The PRG Calculator equation input assumes no ingestion of homegrown produce, due to the institutional control that applies to all Parcels named above that prohibits homegrown plants except in raised beds with imported soil.

5. The size of a survey unit is up to 1,000 $m^2$. Section 4.10.5 of the *PRG Calculator Users Guide* states the following:

   "The RAGS/HHEM [Risk Assessment Guidance for Superfund/Human Health Evaluation Manual] Part B model assumes that an individual is exposed to a source geometry that is effectively an infinite slab. The concept of an infinite slab means that the thickness of the contaminated zone and its aerial extent are so large that it behaves as if it were infinite in its physical dimensions. In practice, soil contaminated to a depth greater than about 15 cm and with an aerial extent greater than about 1,000 $m^2$ will create a radiation field comparable to that of an infinite slab. . . . **in most residential settings the assumption of an infinite slab source will result in overly conservative PRGs.** . . ." (U.S. EPA. 2017.)

   As the most conservative option available, to ensure that an infinite plane is the scenario modelled ~~taken into account~~ in the risk calculations, a 1,000,000 $m^2$ Area Correction Factor was used. This is the largest available option in the choices the PRG Calculator allows, and therefore it is the closest to an infinite plane scenario that is possible in the PRG calculator.

6. An area of 420 acres is assumed because that is the size of the portion of the site that is on land, not under water.

4. **Findings/Conclusions**

Using the above site-specific factors, as recommended by the PRG Calculator Users Guide, Table 1 shows the risk estimate from the current version of the soil PRG Calculator for the ROD RG's. The table also estimates the PRG's at a $10^{-4}$ risk.

**Table 1**
**Residential use PRGs for soil, site-specific factors, realistic scenario[a]**
**For concentrations found above background levels**
**Hunters Point Naval Shipyard, San Francisco, California**
**[Need to replace with new Lyndsey calculations 6/12/2017]**

Formatted Table

| ~~Isotope~~ | ~~Preliminary Remediation Goal (PRG) (pCi/g) at $10^{-4}$ risk[b]~~ | ~~Residential ROD RG's for soil (pCi/g)[c]~~ | ~~Total Risk at ROD RGs~~ |
|---|---|---|---|
| ~~Americium-241 (Am-241)~~ | ~~7.16~~ | ~~1.36~~ | ~~$1.90 X 10^{-5}$~~ |
| ~~Cobalt-60 (Co-60)~~ | ~~1.14~~ | ~~0.0361~~ | ~~$3.16 X 10^{-6}$~~ |
| ~~Cesium-137 (Cs-137)~~ | ~~5.65~~ | ~~0.113~~ | ~~$2.00 X 10^{-6}$~~ |
| ~~Europium-152 (Eu-152)~~ | ~~2.63~~ | ~~0.13~~ | ~~$4.94 X 10^{-6}$~~ |
| ~~Europium-154 (Eu-154)~~ | ~~2.43~~ | ~~2.59~~ | ~~$9.46 X 10^{-6}$~~ |
| ~~Tritium (Hydrogen-3) (H-3)~~ | ~~N/A[d]~~ | ~~2.28~~ | ~~N/A[d]~~ |
| ~~Plutonium-239 (Pu-239)~~ | ~~6.21~~ | ~~2.59~~ | ~~$4.17 X 10^{-5}$~~ |
| ~~Radium-226 (Ra-226)~~ | ~~1.69~~ | ~~1.0~~ | ~~$5.90 X 10^{-5}$~~ |
| ~~Strontium-90 (Sr-90)~~ | ~~746~~ | ~~0.331~~ | ~~$4.43 X 10^{-8}$~~ |
| ~~Thorium-232 (Th-232)~~ | ~~1.24~~ | ~~1.69~~ | ~~$1.36 X 10^{-4}$~~ |
| ~~Uranium-235 (U-235)~~ | ~~6.21~~ | ~~0.195~~ | ~~$3.14 X 10^{-6}$~~ |
| ~~Total Risk if all Radionuclides of Concern were present at ROD RG levels in the same location~~ | | | ~~$2.78 X 10^{-4}$~~ |

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Notes about the table:

a. This estimate uses the default values for the time of day spent indoors vs. outdoors, the duration of residence at one location, and any other values that are not discussed in the section in the "Site-Specific Factors" section above. See Appendix C for the full set of assumptions.

b. The column with "PRGs" mean the concentrations that would be associated with a 1 X $10^{-4}$ risk.

c. The RG's represent concentrations above background concentrations. See Appendix A for more information about background concentrations. USEPA's "Radiation Risk

Assessment at CERCLA Sites Q&A" states "Site characterization efforts should be directed to confirming or refuting the presence of the radionuclides of concern in on-site sources and in environmental media contaminated by releases migrating or being transported and dumped off-site. The activity concentrations of radionuclides (and decay products, if appropriate) in each medium should then be compared with site-specific background concentrations of those radionuclides (i.e., radionuclide concentrations in environmental media not related to site operations or releases), Preliminary Remediation Goals (PRGs), screening levels, or potential remediation criteria (see Q3). Caution should be exercised in making these comparisons, since radionuclide concentrations in environmental media may change over time due to radioactive decay and ingrowth; therefore, consideration should be given to the radioactive half-life of the radionuclides of concern and any decay products, and the time period over which risks will be evaluated." (EPA, 2014)

d. The Health Physics Society states the following about the health effects of tritium:

"The beta particle that is emitted by tritium is considered to be very weak, having an average kinetic energy of 6 keV. As a result, these particular beta particles can only travel about 6 mm in air before they lose their ability to cause ionizations. In tissue, tritium's beta particle is so weak that it cannot penetrate the typical thickness of the dead layer of skin that exists on the outside of the human body." (Health Physics Society, 2011)

With no ingestion or inhalation pathway due to institutional controls, tritium will not be expected to pose a health risk.

Using this realistic scenario, the current version of the soil Rad PRG calculator shows that the risks associated with Remedial Goals fall within the NCP risk range of $10^{-4}$ to $10^{-6}$. Typically, individual survey units would contain two to four RoC's. [move to appendix] USEPA found that in addition, even if all HPNS RoC's were present at the Remedial Goal concentrations, the total combined risk would also still fall with within the risk range of $10^{-4}$ to $10^{-6}$. As a practical matter, usually a given survey unit contains two to four Radionuclides of Concern, so the total risk would fall below this level.

For further context, Appendix D shows similar calculations for these other scenarios:

D.1. Residential soil exposure scenario with no durable cover

D.2. Worker exposure with no durable cover

D.3. Recreational exposure with durable cover

## 5. References


Geosyntec, Inc. 2015. Risk Management Plan Hunters Point Naval Shipyard Parcels UC-1 and UC-2, San Francisco, California. March.

Health Physics Society. 2011. Tritium Fact Sheet. http://hps.org/documents/tritium_fact_sheet.pdf.

Navy. 2006. Final Basewide Radiological Removal Action, Action Memorandum – Revision 2006, Hunters Point Shipyard, San Francisco, California. April 21.

Navy. 2009. Final Amended Parcel B Record of Decision, Hunters Point Shipyard, San Francisco, California. January 26.

Navy. 2010. Remedial Design Package, Parcel B (Excluding Installation Restoration Sites 7 and 18), Hunters Point Shipyard, San Francisco, California. December 10.

Navy. 2011. Radiological Addendum to the Remedial Investigation/Feasibility Study Report for Parcel E-2, Hunters Point Shipyard, San Francisco, California. March.

Navy. 2012. Final Radiological Removal Action Completion Report. March 2.

~~Navy, 2015a. Final Survey Unit Project Reports Abstract for Parcel C, SS/SD Removal Containing NORM Conducted After March 1, 2013, Hunters Point Naval Shipyard, San Francisco, California. May 5.~~

Navy. 2015b. Final Work Plan, Basewide Radiological Support, Hunters Point Naval Shipyard, San Francisco, California. August.

USEPA. 1997. Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination, OSWER No. 9200.4-18. August 22. [ HYPERLINK "http://www.epa.gov/superfund/health/contaminants/radiation/pdfs/radguide.pdf" \h ]

USEPA. 2014. Radiation Risk Assessment at CERCLA Sites Q&A. Office of Emergency and Remedial Response and Office of Radiation and Indoor Air. Washington, DC. OSWER No. 9285.6-20.

USEPA. 2017. Preliminary Remediation Goals for Radionuclides Users Guide. Updated January, 2017, Accessed March 14, 2017. [ HYPERLINK "https://epa-prgs.ornl.gov/radionuclides/PRG_UsersGuide.pdf" ]

**Appendix A:**

USEPA Guidance states the following:

> "Background radiation levels will generally be determined as background levels are determined for other contaminants, on a site-specific basis. In some cases, the same constituents are found in on-site samples as well as in background samples. The levels of each constituent are compared to background to determine its impact, if any, on site- related activities." (USEPA, 1997)

Accordingly, at HPNS, workplans describe the procedures for determining radiological background levels based on reference areas. Background levels vary from location to location, depending on what type of materials are under investigation. Many different fill materials were brought to construct Hunters Point. Additionally, multiple construction events have imported materials that have different background levels. Background is determined based on samples collected at reference areas. These are documented in the Radiological Removal Action Completion Reports (Rad RACRs) and the Survey Unit Project Report Abstracts (SUPRAs) for different sections of the site.

~~[From John: Add the Hunters Point site specific factors for determining background levels]~~

See, for example, the 2015 *Final Work Plan, Basewide Radiological Support*, which states the following:

> "The reference area is a geographical area or structure from which representative radioactivity measurements are performed for comparison with measurements performed in an impacted area. The reference area selected should have physical, chemical, radiological, and biological characteristics similar to the impacted area(s) being investigated. The reference area must not be identified as impacted by the HRA [Historical Radiological Assessment]." (Navy, 2015b)

As one example of this approach, ~~recent~~ measurement of background for a Parcel E-2~~C~~ cleanup effort found the following:

> ~~"Background activity for $^{226}$Ra, based on the mean of the greater of the reported activity or minimum detectable activity (MDA), measured by a minimum of a 21-day in-growth of the 609.31 keV gamma energy peak for bismuth-214 ($^{214}$Bi), was determined to be 1.057 pCi/g. This places the release criterion at 2.057 pCi/g of $^{226}$Ra for final definitive data." (Navy, 2015a)~~
> "Reference (background readings consisted of 16 1-minute static gamma readings taken on the hillside of Parcel A and 16 samples collected at various areas within Parcels B, C, D, and E. . . . Results for samples from the reference areas indicated mean background activity level of 0.049 pCi/g for $^{137}$Cs and 0.82 pCi/g for $^{226}$Ra." (Navy, 2011)

Table A-1 gives a summary of the findings that are presented in more detail in Table 3-3 from the original document, which appears on the next page.

**Table A-1: Concentrations of radionuclides found in reference areas**

~~[Note: Why is the value for Cs-137 negative? Tracy said it's possible that the values shown subtract instrument background. When count time for instrument background is longer than for the soil sample, then negative or~~ zero values can occur.]

| Radionuclide of Concern | Mean background (pCi/g) | Remedial Goal (RG) (pCi/g) | Background + RG (pCi/g) |
|---|---|---|---|
| Ra-226 | 0.049~~1.057~~ | 1.0 | 1.049~~2.057~~ |
| Cs-137 | 0.049~~-0.002~~ | 0.113 | 0.162~~???~~ |
| Sr-90~~Th-232~~ | 0.176~~1.489~~ | 1.69 | ~~3.179~~ |
| ~~U-235~~ | ~~0.121~~ | ~~0.195~~ | ~~0.316~~ |

**Table A-2 Risk estimates associated with the above concentrations using the USEPA PRG Calculator**

[NOTE: Will insert results after finishing calculations]

| Radionuclide of Concern | Mean background | Remedial Goal (RG) | Background + RG |
|---|---|---|---|
| Ra-226 | | | |
| Cs-137 | | | |
| Th-232 | | | |
| U-235 | | | |

## TABLE 3-3

**NORM Fill Material Reference Area Soil Measurements (Definitive)**

Results (pCi/g)

| Sample No. | Date | Time | $^{241}Am$ | MDA | 2σ Total | $^{137}Cs$ | MDA | 2σ Total | $^{60}Co$ | MDA | 2σ Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12/20/2013 | 10:25:00 | -0.089 | 0.192 | 0.236 | -0.013 | 0.028 | 0.035 | 0.001 | 0.025 | 0.031 |
| 2 | 12/20/2013 | 10:27:00 | 0.008 | 0.172 | 0.209 | -0.017 | 0.029 | 0.037 | 0.014 | 0.017 | 0.023 |
| 3 | 12/20/2013 | 10:29:00 | -0.021 | 0.214 | 0.261 | 0.016 | 0.016 | 0.022 | -0.001 | 0.025 | 0.030 |
| 4 | 12/20/2013 | 10:30:00 | 0.116 | 0.180 | 0.224 | -0.015 | 0.028 | 0.035 | -0.005 | 0.025 | 0.030 |
| 5 | 12/20/2013 | 10:31:00 | -0.008 | 0.216 | 0.262 | -0.002 | 0.023 | 0.028 | -0.001 | 0.025 | 0.031 |
| 6 | 12/20/2013 | 10:32:00 | 0.063 | 0.156 | 0.194 | 0.006 | 0.025 | 0.031 | 0.001 | 0.012 | 0.018 |
| 7 | 12/20/2013 | 10:33:00 | 0.086 | 0.177 | 0.214 | -0.004 | 0.022 | 0.027 | 0.001 | 0.024 | 0.012 |
| 8 | 12/20/2013 | 10:34:00 | -0.042 | 0.196 | 0.240 | -0.010 | 0.025 | 0.031 | 0.011 | 0.018 | 0.020 |
| 9 | 12/20/2013 | 10:35:00 | 0.005 | 0.178 | 0.217 | -0.008 | 0.026 | 0.033 | 0.007 | 0.022 | 0.028 |
| 10 | 12/20/2013 | 10:36:00 | -0.109 | 0.227 | 0.280 | 0.006 | 0.028 | 0.032 | -0.005 | 0.024 | 0.030 |
| 11 | 12/20/2013 | 10:37:00 | -0.059 | 0.175 | 0.215 | 0.012 | 0.024 | 0.030 | -0.005 | 0.024 | 0.030 |
| 12 | 12/20/2013 | 10:38:00 | 0.035 | 0.159 | 0.195 | -0.006 | 0.026 | 0.032 | -0.007 | 0.027 | 0.034 |
| 13 | 12/20/2013 | 10:39:00 | 0.100 | 0.202 | 0.251 | -0.005 | 0.026 | 0.032 | -0.002 | 0.027 | 0.033 |
| 14 | 12/20/2013 | 10:40:00 | 0.006 | 0.223 | 0.271 | 0.000 | 0.024 | 0.029 | 0.006 | 0.018 | 0.024 |
| 15 | 12/20/2013 | 10:41:00 | 0.000 | 0.206 | 0.258 | 0.010 | 0.025 | 0.032 | 0.004 | 0.027 | 0.022 |
| 16 | 12/20/2013 | 10:42:00 | -0.049 | 0.200 | 0.245 | 0.007 | 0.026 | 0.032 | -0.003 | 0.024 | 0.030 |
| 17 | 12/20/2013 | 10:43:00 | 0.041 | 0.172 | 0.211 | -0.012 | 0.030 | 0.038 | 0.004 | 0.026 | 0.010 |
| 18 | 12/20/2013 | 10:44:00 | -0.002 | 0.207 | 0.252 | 0.000 | 0.025 | 0.030 | -0.010 | 0.024 | 0.031 |
| | | mean | 0.001 | | | -0.002 | | | 0.001 | | |
| | | std dev | 0.060 | | | 0.010 | | | 0.006 | | |
| | | median | 0.000 | | | -0.003 | | | 0.000 | | |

| Sample No. | $^{226}Ra$ | MDA | 2σ Total | $^{232}Th$ | MDA | 3σ Total | $^{235}U$ | MDA | 2σ Total |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.105 | 0.046 | 0.129 | 1.536 | 0.076 | 0.202 | 0.108 | 0.193 | 0.060 |
| 2 | 1.175 | 0.056 | 0.147 | 1.922 | 0.039 | 0.236 | 0.234 | 0.149 | 0.197 |
| 3 | 1.062 | 0.052 | 0.135 | 1.493 | 0.045 | 0.198 | 0.118 | 0.216 | 0.061 |
| 4 | 1.060 | 0.053 | 0.133 | 1.497 | 0.074 | 0.178 | 0.129 | 0.201 | 0.061 |
| 5 | 0.983 | 0.050 | 0.128 | 1.378 | 0.085 | 0.204 | 0.126 | 0.262 | 0.055 |
| 6 | 0.924 | 0.054 | 0.132 | 1.165 | 0.079 | 0.150 | 0.076 | 0.187 | 0.056 |
| 7 | 0.945 | 0.046 | 0.125 | 1.352 | 0.073 | 0.201 | 0.154 | 0.162 | 0.221 |
| 8 | 1.074 | 0.058 | 0.142 | 1.310 | 0.073 | 0.172 | 0.181 | 0.171 | 0.216 |
| 9 | 0.867 | 0.053 | 0.127 | 1.408 | 0.027 | 0.200 | 0.037 | 0.192 | 0.042 |
| 10 | 1.091 | 0.050 | 0.129 | 1.744 | 0.068 | 0.193 | 0.105 | 0.210 | 0.049 |
| 11 | 1.112 | 0.044 | 0.124 | 1.804 | 0.075 | 0.165 | 0.135 | 0.193 | 0.048 |
| 12 | 0.967 | 0.057 | 0.144 | 1.349 | 0.078 | 0.208 | 0.124 | 0.192 | 0.049 |
| 13 | 1.053 | 0.054 | 0.133 | 1.456 | 0.088 | 0.185 | 0.100 | 0.171 | 0.046 |
| 14 | 0.986 | 0.045 | 0.121 | 1.585 | 0.069 | 0.163 | 0.076 | 0.199 | 0.063 |
| 15 | 0.966 | 0.048 | 0.130 | 1.445 | 0.061 | 0.203 | 0.114 | 0.226 | 0.048 |
| 16 | 1.103 | 0.042 | 0.133 | 1.286 | 0.099 | 0.188 | 0.104 | 0.207 | 0.046 |
| 17 | 1.381 | 0.050 | 0.151 | 1.519 | 0.098 | 0.185 | 0.126 | 0.212 | 0.048 |
| 18 | 1.177 | 0.053 | 0.140 | 1.469 | 0.080 | 0.181 | 0.123 | 0.197 | 0.049 |
| mean | 1.057 | | | 1.489 | | | 0.121 | | |
| std dev | 0.118 | | | 0.190 | | | 0.042 | | |
| median | 1.061 | | | 1.463 | | | 0.121 | | |

*Notes:*

Information concerning flags associated with the on-site laboratory data can be found in Section 4.3.

***Abbreviations and Acronyms:***

$^{137}Cs$ – cesium-137
MDA – minimum detectable activity
MDC – minimum detectable concentration
pCi/g – picocuries per gram
$^{226}Ra$ – radium-226
std dev – standard deviation
$^{232}Th$ – thorium-232

(Navy, 2015a)

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## Appendix B: Converting 26-inch Asphalt and 4-inch aggregate base course -to a Soil Depth

[Replace with Lyndsey's new calculations 6/12/2017]
The basic shielding calculation is:

$$I_f = I_0 e^{-\mu_L t}$$

Where $I_f$ is the final intensity of radiation,
$I_0$ is the original intensity of radiation
$\mu_L$ is the linear attenuation coefficient of the material attenuating the radiation, and
t is the thickness of the attenuator

If we divide by $I_0$, we get the fraction of intensity that has been attenuated when passing through a specific absorber of a specific thickness (t).

$$\frac{I_f}{I_0} = e^{-\mu_L t}$$

If we use soil, the fraction of intensity equation would look like the following:

$$\frac{I_{f,soil}}{I_{0,soil}} = e^{-\mu_{L,soil} t_{soil}}$$

Likewise, if we use asphalt, the fraction of intensity equation would look like the following:

$$\frac{I_{f,asphalt}}{I_{0,asphalt}} = e^{-\mu_{L,asphalt} t_{asphalt}}$$

For Hunter's Point, we want to determine how much soil would give us the same fraction of intensity as 6inches of asphalt. To determine the depth of soil needed, we will set both the fraction of intensity of soil and asphalt equal to each other as followed:

$$e^{-\mu_{L,soil} t_{soil}} = \frac{I_{f,soil}}{I_{0,soil}} = \frac{I_{f,asphalt}}{I_{0,asphalt}} = e^{-\mu_{L,asphalt} t_{asphalt}}$$

If we cancel out the intensity fraction, this would give us:

$$e^{\mu_{L,soil} t_{soil}} = e^{\mu_{L,asphalt} t_{asphalt}}$$

To eliminate the exponential, we multiply each side by natural log of each side.

$$ln(e^{\mu_{L,soil} t_{soil}}) = ln(e^{\mu_{L,asphalt} t_{asphalt}})$$

This would give us:

$$\mu_{L,soil} t_{soil} = \mu_{L,asphalt} t_{asphalt}$$

If we solve to $t_{soil}$, this would give us the equation needed to determine the depth of soil needed to equal 6 inches of asphalt.

$$t_{soil} = \frac{\mu_{L,asphalt} t_{asphalt}}{\mu_{L,soil}}$$

In order to solve the above equation, we must know the linear attenuation coefficient for soil and asphalt. The linear attenuation coefficient is determined by specific energies. If we look at a lower energy such as 0.186MeV for Ra-226, we get the following

$$t_{soil} = \frac{\mu_{L,asphalt} t_{asphalt}}{\mu_{L,soil}}$$

where the $t_{asphalt}$=6 inches = 15.24 cm
$\mu_{L,asphalt}$ = 0.307 $cm^{-1}$
$\mu_{L,soil}$ = 0.195 $cm^{-1}$

$$t_{soil} = \frac{0.307\ cm^{-1} \times 15.24\ cm}{0.195\ cm^{-1}}$$

$$t_{soil} = 23.99$$

If we look at a higher energy such as 2.614MeV for Tl-208, we get the following:

$$t_{soil} = \frac{0.0916 cm^{-1} \times 15.24 cm}{0.0541\ cm^{-1}}$$

$$t_{soil} = 25.79$$

**Appendix C: PRG Calculator Site-Specific Resident Equation Inputs for Soil**

This receptor spends most, if not all, of the day at home except for the hours spent at work. The activities for this receptor involve typical home making chores (cooking, cleaning and laundering). The resident is assumed to be exposed to contaminants via external radiation from contaminants in soil.

**Site-Specific**
**Resident Equation Inputs for Soil**

| Variable | Value |
|---|---|
| TR (target cancer risk) unitless | 0.0001 |
| t (time - resident) yr | 26 |
| ED (exposure duration - resident) yr | 26 |
| ET (exposure time - resident) hr/day | 24 |
| ET (exposure time - resident child) hr/day | 24 |
| ET (exposure time - resident adult) hr/day | 24 |
| ET (exposure time - indoor resident) hr/day | 16.416 |
| ET (exposure time - outdoor resident) hr/day | 1.752 |
| ED (exposure duration - resident child) yr | 6 |
| ED (exposure duration - resident adult) yr | 20 |
| EF (exposure frequency - resident) day/yr | 350 |
| EF (exposure frequency - resident child) day/yr | 350 |
| EF (exposure frequency - resident adult) day/yr | 350 |
| IRS (soil intake rate - resident adult) mg/day | 0 |
| IRS (soil intake rate - resident child) mg/day | 0 |
| IRA (inhalation rate - resident adult) $m^3$/day | 0 |
| IRA (inhalation rate - resident child) $m^3$/day | 0 |
| IFS (age-adjusted soil ingestion factor - resident) mg | 0 |
| IFA (age-adjusted soil inhalation factor - resident) $m^3$ | 0 |
| GSF (gamma shielding factor - indoor) unitless | 0.4 |
| Site area for ACF (area correction factor) $m^2$ | 1000029 |
| Cover thickness for GSF (gamma shielding factor) cm | 20 |
| IRAP (apple ingestion rate - resident adult) g/day | 73.7 |
| IRAP (apple ingestion rate - resident child) g/day | 72.2 |
| IFAP (age-adjusted apple ingestion factor) g | 0 |
| IRCI (citrus ingestion rate - resident adult) g/day | 309.4 |
| IRCI (citrus ingestion rate - resident child) g/day | 194.1 |
| IFCI (age-adjusted citrus ingestion factor) g | 0 |
| IRBE (berry ingestion rate - resident adult) g/day | 35.4 |
| IRBE (berry ingestion rate - resident child) g/day | 23.9 |
| IFBE (age-adjusted berry ingestion factor) g | 0 |
| IRPC (peach ingestion rate - resident adult) g/day | 115.7 |
| IRPC (peach ingestion rate - resident child) g/day | 111.4 |
| IFPC (age-adjusted peach ingestion factor) g | 0 |

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## Site-Specific
Resident Equation Inputs for Soil

| Variable | Value |
|---|---|
| IRPR... (pear ingestion rate - resident adult) g/day | 51.9 |
| IRPR... (pear ingestion rate - resident child) g/day | 66.7 |
| IFPR... (age-adjusted pear ingestion factor) g | 0 |
| IRST... (strawberry ingestion rate - resident adult) g/day | 40.5 |
| IRST... (strawberry ingestion rate - resident child) g/day | 25.3 |
| IFST... (age-adjusted strawberry ingestion factor) g | 0 |
| IRAS... (asparagus ingestion rate - resident adult) g/day | 39.3 |
| IRAS... (asparagus ingestion rate - resident child) g/day | 12.0 |
| IFAS... (age-adjusted asparagus ingestion factor) g | 0 |
| IRBT... (beet ingestion rate - resident adult) g/day | 33.9 |
| IRBT... (beet ingestion rate - resident child) g/day | 3.9 |
| IFBT... (age-adjusted beet ingestion factor) g | 0 |
| IRBR... (broccoli ingestion rate - resident adult) g/day | 32.0 |
| IRBR... (broccoli ingestion rate - resident child) g/day | 13.1 |
| IFBR... (age-adjusted broccoli ingestion factor) g | 0 |
| IRCB... (cabbage ingestion rate - resident adult) g/day | 92.1 |
| IRCB... (cabbage ingestion rate - resident child) g/day | 12.3 |
| IFCB... (age-adjusted cabbage ingestion factor) g | 0 |
| IRCR... (carrot ingestion rate - resident adult) g/day | 27.3 |
| IRCR... (carrot ingestion rate - resident child) g/day | 14.9 |
| IFCR... (age-adjusted carrot ingestion factor) g | 0 |
| IRCO... (corn ingestion rate - resident adult) g/day | 59.8 |
| IRCO... (corn ingestion rate - resident child) g/day | 23.8 |
| IFCO... (age-adjusted corn ingestion factor) g | 0 |
| IRCU... (cucumber ingestion rate - resident adult) g/day | 82.4 |
| IRCU... (cucumber ingestion rate - resident child) g/day | 25.4 |
| IFCU... (age-adjusted cucumber ingestion factor) g | 0 |
| IRLE... (lettuce ingestion rate - resident adult) g/day | 37.5 |
| IRLE... (lettuce ingestion rate - resident child) g/day | 4.2 |
| IFLE... (age-adjusted lettuce ingestion factor) g | 0 |
| IRLI... (lima bean ingestion rate - resident adult) g/day | 33.8 |
| IRLI... (lima bean ingestion rate - resident child) g/day | 6.5 |
| IFLI... (age-adjusted lima bean ingestion factor) g | 0 |
| IROK... (okra ingestion rate - resident adult) g/day | 30.2 |

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## Site-Specific
### Resident Equation Inputs for Soil

| Variable | Value |
|---|---|
| IROK (okra ingestion rate - resident child) g/day | 5.3 |
| IFOK (age-adjusted okra ingestion factor) g | 0 |
| IRON (onion ingestion rate - resident adult) g/day | 21.8 |
| IRON (onion ingestion rate - resident child) g/day | 5.8 |
| IFON (age-adjusted onion ingestion factor) g | 0 |
| IRPE (pea ingestion rate - resident adult) g/day | 35.4 |
| IRPE (pea ingestion rate - resident child) g/day | 32.1 |
| IFPE (age-adjusted pea ingestion factor) g | 0 |
| IRPU (pumpkin ingestion rate - resident adult) g/day | 64.8 |
| IRPU (pumpkin ingestion rate - resident child) g/day | 45.2 |
| IFPU (age-adjusted pumpkin ingestion factor) g | 0 |
| IRSN (snap bean ingestion rate - resident adult) g/day | 53.9 |
| IRSN (snap bean ingestion rate - resident child) g/day | 27.3 |
| IFSN (age-adjusted snap bean ingestion factor) g | 0 |
| IRTO (tomato ingestion rate - resident adult) g/day | 80.3 |
| IRTO (tomato ingestion rate - resident child) g/day | 29.7 |
| IFTO (age-adjusted tomato ingestion factor) g | 0 |
| IRPT (potato ingestion rate - resident adult) g/day | 127.8 |
| IRPT (potato ingestion rate - resident child) g/day | 51.7 |
| IFPT (age-adjusted potato ingestion factor) g | 0 |
| IRRI (rice ingestion rate - resident adult) g/day | 73.2 |
| IRRI (rice ingestion rate - resident child) g/day | 28.8 |
| IFRI (age-adjusted rice ingestion factor) g | 0 |
| IRCG (cereal grain ingestion rate - resident adult) g/day | 76.0 |
| IRCG (cereal grain ingestion rate - resident child) g/day | 38.0 |
| IFCG (age-adjusted cereal grain ingestion factor) g | 611800 |
| CF (contaminated plant fraction) unitless | 1 |
| CF (contaminated apple fraction) unitless | 1 |
| CF (contaminated citrus fraction) unitless | 1 |
| CF (contaminated berry fraction) unitless | 1 |
| CF (contaminated peach fraction) unitless | 1 |
| CF (contaminated pear fraction) unitless | 1 |
| CF (contaminated strawberry fraction) unitless | 1 |
| CF (contaminated asparagus fraction) unitless | 1 |

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## Site-Specific
### Resident Equation Inputs for Soil

| Variable | Value |
|---|---|
| CF (contaminated beet fraction) unitless | 1 |
| CF (contaminated broccoli fraction) unitless | 1 |
| CF (contaminated cabbage fraction) unitless | 1 |
| CF (contaminated carrot fraction) unitless | 1 |
| CF (contaminated corn fraction) unitless | 1 |
| CF (contaminated cucumber fraction) unitless | 1 |
| CF (contaminated lettuce fraction) unitless | 1 |
| CF (contaminated lima bean fraction) unitless | 1 |
| CF (contaminated okra fraction) unitless | 1 |
| CF (contaminated onion fraction) unitless | 1 |
| CF (contaminated pea fraction) unitless | 1 |
| CF (contaminated pumpkin fraction) unitless | 1 |
| CF (contaminated snap bean fraction) unitless | 1 |
| CF (contaminated tomato fraction) unitless | 1 |
| CF (contaminated potato fraction) unitless | 1 |
| CF (contaminated rice fraction) unitless | 1 |
| CF (contaminated cereal grain fraction) unitless | 1 |
| MLF (apple mass loading factor) unitless | .000160 |
| MLF (citrus mass loading factor) unitless | .000157 |
| MLF (berry mass loading factor) unitless | .000166 |
| MLF (peach mass loading factor) unitless | .000150 |
| MLF (pear mass loading factor) unitless | .000160 |
| MLF (strawberry mass loading factor) unitless | .0000800 |
| MLF (asparagus mass loading factor) unitless | .0000790 |
| MLF (beet mass loading factor) unitless | .000138 |
| MLF (broccoli mass loading factor) unitless | .00101 |
| MLF (cabbage mass loading factor) unitless | .000105 |
| MLF (carrot mass loading factor) unitless | .0000970 |
| MLF (corn mass loading factor) unitless | .000145 |
| MLF (cucumber mass loading factor) unitless | .0000400 |
| MLF (lettuce mass loading factor) unitless | .0135 |
| MLF (lima bean mass loading factor) unitless | .00383 |
| MLF (okra mass loading factor) unitless | .0000800 |
| MLF (onion mass loading factor) unitless | .0000970 |

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## Site-Specific
### Resident Equation Inputs for Soil

| Variable | Value |
|---|---|
| MLF (pea mass loading factor) unitless | .000178 |
| MLF (pumpkin mass loading factor) unitless | .0000580 |
| MLF (snap bean mass loading factor) unitless | .00500 |
| MLF (tomato mass loading factor) unitless | .00159 |
| MLF (potato mass loading factor) unitless | .000210 |
| MLF (rice mass loading factor) unitless | .250 |
| MLF (cereal grain mass loading factor) unitless | .250 |
| TR (target cancer risk) unitless | 0.0001 |
| ED (exposure duration - resident child) yr | 0 |
| ED (exposure duration - resident adult) yr | 0 |
| EF (exposure frequency - resident child) day/yr | 0 |
| EF (exposure frequency - resident adult) day/yr | 0 |
| City (Climate Zone) | 26 |
| A (acres) | 500 |
| Q/C (g/m$^2$-s per kg/m$^3$) | 31.690869932192 |
| PEF (particulate emission factor) m ³/kg | 9986605274.2569 |
| A (PEF Dispersion Constant) | 13.8139 |
| B (PEF Dispersion Constant) | 20.1624 |
| C (PEF Dispersion Constant) | 234.2869 |
| V (fraction of vegetative cover) unitless | 0.8 |
| U (mean annual wind speed) m/s | 3.89 |
| U (equivalent threshold value) | 11.32 |
| F(x) (function dependant on U /U) unitless | 0.0391 |

## Appendix D: Risk estimates and Preliminary Remediation Goals (PRG's) associated with other scenarios

As additional background information for context, below are results showing risk estimates and Preliminary Remediation Goal (PRG) levels for different scenarios:

D.1. Residential soil exposure scenario with no durable cover

D.2. Worker exposure with no durable cover

D.3. Recreational exposure with durable cover

Details appear below. Note that PRGs refer to concentrations found above background levels.

**D.1. Residential soil exposure scenario with no durable cover**

This receptor spends most, if not all, of the day at home except for the hours spent at work. The activities for this receptor involve typical home making chores (cooking, cleaning and laundering) as well as gardening. The resident is assumed to be exposed to contaminants via the following pathways: incidental ingestion of soil, external radiation from contaminants in soil, and inhalation of fugitive dust. Adults and children exhibit different ingestion rates for soil. For example, the child resident is assumed to ingest 200 mg per day while the adult ingests 100 mg per day. To take into account the different intake rate for children and adults, age adjusted intake equations were developed to account for changes in intake as the receptor ages.

[Insert Summary Table of PRG's and Risks]

**D.2. Construction Worker exposure with no durable cover**

This is a long-term receptor exposed during the work day who is a full time employee working on-site and who spends most of the workday conducting maintenance activities outdoors. The activities for this receptor (e.g., moderate digging, landscaping) typically involve on-site exposures to surface soils. The composite worker is expected to have an elevated soil ingestion rate (100 mg per day) and is assumed to be exposed to contaminants via the following pathways: incidental ingestion of soil, external radiation from contaminants in soil, inhalation of fugitive dust . The composite worker combines the most protective exposure assumptions of the outdoor and indoor workers. The only difference between the outdoor worker and the composite worker is that the composite worker uses the more protective exposure frequency of 250 days/year from the indoor worker scenario.

[Insert Summary Table of PRG's and Risks]

**D.3. Recreational exposure with durable cover**

This receptor spends time outside involved in recreational activities.

[Insert Summary Table of PRG's and Risks]